

WHAT IS CLAIMED IS:

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1 1. An audio system for use in a vehicle having a roof, the system
2 comprising:
3 an acoustically-insulating headliner adapted to be mounted adjacent
4 the roof so as to underlie the roof and shield the roof from view, the headliner
5 having an upper surface and a sound-radiating, lower surface;
6 a source of audio signals;
7 an array of electromagnetic transducer assemblies supported at the
8 upper surface of the headliner;
9 signal processing circuitry coupled to the assemblies for processing
10 the audio signals to obtain processed audio signals wherein the assemblies convert
11 the processed audio signals into mechanical motion of corresponding zones of the
12 headliner and wherein the headliner is made of a material which is sufficiently stiff
13 and low in density so that the headliner radiates acoustic power into the interior of
14 the vehicle with a frequency range defined by a lower limit of 100 hertz or less and
15 an upper limit of 12 kilohertz or more and the processed audio signals at a low end
16 of the frequency range are matched to the processed audio signals at mid and high
17 ends of the frequency range.

1 2. The system as claimed in claim 1 wherein the vehicle has a
2 windshield and wherein the array of electromagnetic transducer assemblies includes
3 at least one row of electromagnetic transducer assemblies adjacent the windshield
4 and wherein the at least one row of electromagnetic transducer assemblies are
5 positioned 5 to 30 inches in front of an expected position of a passenger in the
6 interior of the vehicle.

1 3. The system as claimed in claim 2 wherein the at least one row
2 of electromagnetic transducer assemblies are positioned 12 to 24 inches in front of
3 the expected position of the passenger.

1 4. The system as claimed in claim 2 wherein the at least one row
2 of electromagnetic transducer assemblies includes at least two electromagnetic

3 transducer assemblies spaced apart to correspond to left and right ears of the
4 passenger in the expected position of the passenger.

1 5. The system as claimed in claim 1 wherein each of the
2 electromagnetic transducer assemblies includes a magnet for establishing a magnetic
3 field in a gap formed within the assembly, a coil which moves relative to the magnet
4 in response to the processed audio signals, a base fixedly secured to the headliner on
5 the upper surface and electrically connected to the signal processing circuitry and a
6 guide member electrically connected to the coil and removably secured to the base
7 for supporting the coil in the gap and wherein the coils are electrically coupled to the
8 signal processing circuit when the guide members are secured to their corresponding
9 bases.

1 6. The system as claimed in claim 5 wherein each of the magnets
2 is a high-energy permanent magnet.

1 7. The system as claimed in claim 6 wherein each of the high-
2 energy permanent magnets is a rare-earth magnet.

1 8. The system as claimed in claim 5 wherein each of the
2 assemblies includes a spring element having a resonant frequency below the lower
3 limit of the frequency range when incorporated within its assembly and connected
4 to its corresponding guide member for resiliently supporting its corresponding
5 magnet above the upper surface of the headliner.

1 9. The system as claimed in claim 1 wherein the array of
2 electromagnetic transducer assemblies includes a front row of electromagnetic
3 transducer assemblies positioned 5 to 30 inches in front of an expected position of
4 a passenger in the interior of the vehicle and a back row of electromagnetic
5 transducer assemblies positioned behind the expected position of the passenger
6 wherein the signal processing circuitry delays the audio signals coupled to the back
7 row of electromagnetic transducer assemblies relative to the audio signals coupled
8 to the front row of electromagnetic transducer assemblies.

1 10. The system as claimed in claim 1 wherein the array of
2 electromagnetic transducer assemblies are completely supported on the upper surface
3 of the headliner.

1 11. The system as claimed in claim 1 further comprising at least
2 one loudspeaker coupled to the signal processing circuitry, and adapted to be placed
3 in the interior of the vehicle in front of an expected position of a passenger and
4 below the headliner.

1 12. The system as claimed in claim 1 wherein the headliner
2 material has a stiffness between 1E9PA and 5E9PA and a density of between 100
3 and 800 kilograms per meter cubed.

1 13. The system as claimed in claim 1 wherein the electromagnetic
2 transducer assemblies are spaced to the left and right, front and rear of expected
3 positions of passengers in the interior of the vehicle to create proper audio imaging
4 for the passengers.

1 14. The system as claimed in claim 1 further comprising at least
2 one loudspeaker positioned in front of expected positions of passengers below the
3 headliner but not in doors, kick panels, or under a dash of the vehicle.

1 15. The system as claimed in claim 1 further comprising a low
2 frequency speaker positioned below the headliner in the interior of the vehicle.

1 16. The system as claimed in claim 1 wherein the array has front
2 and rear assemblies and wherein each rear electromagnetic transducer assembly is
3 coupled to processed audio signals delayed in time relative to the processed audio
4 signals coupled to each front electromagnetic transducer assembly.

1 17. The system as claimed in claim 1 wherein the audio signals are
2 processed with head-related transfer functions by the signal processing circuitry.

1 18. The system as claimed in claim 1 wherein the electromagnetic
2 transducer assemblies are supported only on the headliner.

1 19. The system as claimed in claim 1 wherein the headliner is self-
2 supporting.

1 20. The system as claimed in claim 1 further comprising a semi-
2 compliant attachment mechanism adapted to attach the headliner to the roof along at
3 least a substantial periphery of the roof.

1 21. The system as claimed in claim 1 further comprising a semi-
2 compliant attachment mechanism adapted to attach the headliner to the roof along at
3 least a substantial periphery of the roof and a central portion of the roof.

1 22. The system as claimed in claim 1 further comprising a support
2 structure for reinforcing the headliner.

1 23. The system as claimed in claim 1 further comprising framing
2 independent of the headliner to support the assemblies.

1 24. The system as claimed in claim 1 wherein the headliner
2 material has a stiffness (modulus of elasticity, Youngs modulus) between 1E9 Pa and
3 5e9 Pa and a density between 100 and 800 Kg/m³ and wherein the headliner
4 material may be made from single materials or composites.

1 25. The system as claimed in claim 1 wherein stiffness and density
2 of the headliner material is altered around the entire periphery of the headliner to
3 allow for additional excursion of the entire headliner in order to create better low
4 frequency reproduction (<200 Hz) of the processed audio signals.

1 33. The system as claimed in claim 1 wherein each of the
2 electromagnetic transducer assemblies includes a subassembly having vibrational
3 characteristics and adapted to be screwed, snapped, or twisted into position at the

4 upper surface of the headliner, and wherein vibrational characteristics of each of the
5 subassemblies can be tested for performance and quality prior to its installation on
6 the headliner.

1 34. The system as claimed in claim 33 wherein each of the
2 assemblies includes a base fixedly secured to the headliner and removably secured
3 to its corresponding subassembly by a mechanical attachment and wherein the
4 mechanical attachment also makes electrical contact between the base and its
5 subassembly.

1 35. The system as claimed in claim 1 wherein the processed audio
2 signals to be delivered to each electromagnetic transducer assembly may be routed
3 to alternate electromagnetic transducer assemblies to achieve different imaging and
4 performance goals, the processed audio signals being monaural, stereo, or multi-
5 channel signals.

1 36. The system as claimed in claim 1 wherein an acoustical center
2 channel signal in a multi-channel setup is achieved by sending a processed center
3 channel signal to both left and the right channel electromagnetic transducer
4 assemblies in a row of electromagnetic transducer assemblies and utilizing
5 mechanical mixing of the headliner to move the headliner between the left and right
6 channel electromagnetic transducer assemblies as a center channel speaker.

1 37. The system as claimed in claim 1 further comprising a
2 compliant material positioned between the assemblies and the roof.

1 38. The system as claimed in claim 1 further comprising at least
2 one microphone positioned in the interior of the vehicle for intra-cabin and extra-
3 cabin communications (cellular, digital, etc).

1 39. The system as claimed in claim 1 wherein the processed audio
2 signals represent global or local vehicle warnings delivered to the entire or local
3 interior sections of the vehicle.

1 40. The system as claimed in claim 1 wherein the signal processing
2 circuitry utilizes adaptive filtering techniques to perform automatic system
3 equalization.

1 41. The system as claimed in claim 1 wherein each area in the
2 interior of the vehicle can be separately equalized.

1 ~~42.~~ An electromagnetic transducer assembly comprising:
2 ~~a~~ subassembly including:
3 a housing;
4 a magnet for establishing a magnetic field within the housing;
5 a coil which moves relative to the magnet in response to an
6 audio signal; and
7 a flexible spider and a guide member for supporting the coil
8 centrally within the magnetic field; and
9 a mating base piece for attaching the subassembly to a vehicle
10 headliner wherein the subassembly is removably secured to the mating base piece by
11 screwing, snapping or twisting.

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